APPENDIX B

SURFACING REQUIREMENTS FOR CONTAINER STORAGE AND MARSHALING AREAS

B-1. Introduction.

Many of the containership terminals are provided with from 12 to 18 acres of container storage and marshaling area per berth. Wheel loads and tire pressures of container handling equipment used at the commercial ports have been determined to be as severe as those of a C-130 aircraft. Therefore, it is absolutely essential that military port planners be able to determine the amount of surfacing that is required so that sufficient resources can be programmed into a base development plan.

B-2. Factors affecting surfacing requirements.

a. Vehicle characteristics. Vehicles with the same load-carrying capabilities may require extremely different surfacing, depending on individual vehicle characteristics. Surfacing requirements vary in type, thickness, and strength in accordance with wheel loads, number of wheels and their arrangement, and tire contact pressure and contact area. Because of this variation in pavement requirements, the engineering construction and maintenance effort may be several times greater for one vehicle than for another with equal load-carrying capability.

b. Traffic volume and flow patterns. Traffic volume is a primary consideration in the selection of the type of surfacing and its required thickness. It is essential that an adequate study be made to determine the number of vehicle passes and the traffic patterns of each vehicle under consideration so that a reasonable design volume for a particular facility and vehicle can be selected.

c. Container selectivity. Container selectivity involves the relative ease with which individual containers can be located and removed from a storage area. If containers are not stacked or are mounted on a chassis, selectivity would normally be considered 100 percent because no other containers would have to be moved in order to locate and remove a specific container from storage. Utilization of space is not particularly efficient, however, if containers are stacked two or three high or in blocks with very little space between containers. Space is masimiT7ed at the expense of selectivity. Both locating a container and removing it from the stack would be difficult. The need for selectivity varies considerably. Empty containers need virtually no degree of selectivity, but containers with car go suitable for throughput need a high degree of selectivity.

d. Area requirements. Another important factor affecting the effort involved in constructing adequate surfacing at military ports is the amount of area to be surfaced. It is extremely important that the total surface area be limited in order to minimize construction and maintenance efforts. Area requirements vary with vehicle characteristics, operational patterns, container sizes and weights, driver skill, number of vehicles, and protective measures taken.

(1) Trends at commercial ports in the United States indicate that up to 18 acres of storage and marshaling area may be required for each containership berth with a minimum retention time of two or three days. With a discharge rate of sixteen 20-foot containers per hour, a storage capacity of 320 containers would represent a one-day, one-direction retention time. Because an equal number of containers must be placed back on the ship, this quantity will double to 640 containers per containership berth per day. If these containers were temporarily stacked on a 40-foot trailer chassis, approximately 8 acres of surfacing would be required. In a chassis operation of this type, the spacing between trailers in rows and the width of aisles could depend on the skill of truck drivers, the load carrying capacity and characteristics of the vehicles. This variation can result in as much as a 20 percent reduction in the number of containers that can be stored per acre. If straddle carriers are employed, the 640 containers can be stacked two high in an area of only 3 acres.

(2) Dispersion or camouflage may, in some instances, be a factor in area requirements. Although camouflage is somewhat limited in effectiveness as a passive defensive measure for military ports, dispersion of materials awaiting shipment out of the port area is an important consideration. The number of required container handling vehicles is drastically increased in a vastly dispersed operation, and the required amount of finished surface area is drastically increased.

e. Staging of construction. Considering the many factors that may affect the construction effort relative to surfacing requirements, the decision confronting the military planner may become one of balancing available engineer and transportation resources. In the early stages of a major base development operation, construction requirements usually greatly exceed the capabilities of available engineer units. Until critically needed facilities such as airfields become operational, all construction must be kept as austere as possible. The use of expedient surfaces such as landing mats is appropriate at this stage of the logistics support operation. The type of mat employed must be capable of withstanding sustained container handling operations over a several-month period without a major maintenance effort. After the demand for engineer troop units become less critical and sources of aggregate have been developed, the mat can be replaced with either flexible or rigid pavement.

B-3. Container handling vehicles.

Efficient handling of large containers requires special equipment. The minor categories of equipment currently being manufactured and capable of handling a container weighing 30 long tons are the forklift (front and side loading), straddle carrier, yard gantry, mobile crape, and tractor-trailer combination. Representative vehicles of each major category are distanced herein.

a. LARC LX. The LARC LX (fig B-1), formerly known as BARC, has the ability to operate on low-strength soils at a gross weight of 319,000 pounds (120,000-pound pay-load). The LARC LX is capable of lightering 40-foot containers, which can be discharged from the LARC by crane, narrow straddle carriers, or rollers similar to those used in unloading cargo aircraft.

b. Shoremaster (straddle carrier). The Shoremaster (fig B-2) is constructed in such a manner as to distribute the load evenly on eight wheels with a maximum single-wheel load of 16,500 pounds at a rated gross weight of 132,000 pounds. This vehicle is also narrow enough (13 feet 3 inches) to negotiate the ramps of a LARC LX (13 feet 8 inches), an LCM (Landing Craft Medium)-VI (14 feet 6 inches), or a 1610 Class LCU (Landing Craft Utility) (14 feet) and has a minimum overhead clearance of 14 feet.

c. Clark 512 (straddle carrier). This vehicle (fig B-3) is widely used in commercial shipping. Its width of 13 feet 6 inches allows it to enter the ramp opening of the LCM-VIII and the 1610 Class LCU.

d. Belotti B67b (straddle carrier). The Belotti B67b (fig B-4) has the ability to hoist 20-foot containers out-board its basic frame. This allows it to stack 20-foot containers three high as well as to load them aboard rail cars. Containers longer than 20 feet can be stacked only two high because they extend beyond the end frame members and cannot be shifted to the side.

e. Hyster H620B (front-loading forklift). This forklift (fig B-5) can handle 50,000-pound containers. The weight is distributed primarily on four front tires having single-wheel loads of 32,600 pounds at a gross vehicle weight of 140,710 pounds.

f. Letro-Porter 2582 (front-loading forklift). This vehicle (fig. 6) is capable of operating on most sandy y beaches; its articulated body also enhances its ability to operate on unsurfaced soils.

g. Lancer 3500 (side-loading forklift). The lacer 3500 (fig. B-7) can handle 30-long-ton container loads. It can transport these containers at 25 miles per hour and stack the containers two high or load them on railroad cam.

h. Travelift CH 1150 (yard gantry). This yard gantry (fig. B-8) has the ability to span six traffic lanes and is equipped with two large tires o each leg that distribute the load imposed by the weight of the gantry. individual containers do not exert highly concentrated loads when stacked on the ground. These of this vehicle would allow five rows of containers to be stacked and require only two treadways and one 10foot traffic lane to be surfaced. It was flit that a yard gentry of this size will permit the greatest concentration of containers for the least construction effort.

i. P&H 6250-TC (mobile crane). This large mobile crane (fig. B-9) offers a quick solution to the problem of converting existing DeLong piers into container handling facilities. Of the four large-capacity truck cranes suitable for container discharge, the P&H 6250 truck crane is the only one that has wide usage in commercial operations at this time.

j. LeTro Crane GC-500 (mobile gantry crane). The portal lower works of this crane (fig. B-10) permits operation on the deck of a DeLong barge while traffic passes beneath it. It is reported to be capable of handling up to 20 containers per hour.

k. M52 Tractor-Trailer. The M52 tractor (fig. B-11) is capable of handling a 20-foot container. However, it doe. not appear to be capable of handling a fully loaded 40-foot commercial container.

B-4. Soil strength and thickness requirements for vehicle operation.

a. Unsurfaced soils. Strength and thickness requirements for Unsurfaced soils can be determined through the us of the nomograph shown in figure B-12 and the following equation:

$$t = (0.176 \log C + 0.12) \sqrt{\frac{P}{8.1\,\mathrm{CBR}} - \frac{A}{\pi}} \quad \text{(B-1)}$$

where

t = thickness of strengthening layer, inches
C = traffic volume, coverages
P = single- or equivalent single-wheel load (ESWL), pounds

CBR = measure of soil strength as determined by Test 101 specified in Military Standard No. MIL-STD-621A, "Test Methods for Pavement Subgrade, Subbase, and Base Course Materials," December 1964.

A = tire contact area, square inches

The CBR and thickness requirements for 200 and 10,000 passes of container handling vehicles operating on unsurfaced soils with subgrade strength of four and ten CBR are contained in table B-1. These requirements may be used as design criteria in accordance with table B-2.

b. Soils beneath landing mat. Strength and thickness requirements for soils beneath landing mat are determined through use of the following equations:

$$\mathbf{CBR} = \frac{P}{8.1\left[\left(\frac{TR}{f}\right)^2 + \frac{A}{\pi}\right]} \qquad \textbf{(B-2)}$$

$$t_{um} = \left[(0.2875 \log C + 0.1875)\sqrt{\frac{P}{8.1\,CBR} - \frac{A}{\pi}}\right] - TR \qquad \textbf{(B-3)}$$

where

TR = thickness of flexible pavement structure replaced by landing mat, inches

f = repetitions factor The soil strength and thickness requirements for container handling vehicles are given in table B-4. These requirements may be used as design criteria in accordance with the restrictions set forth in table B-3.

B-5. Thickness requirements for flexible pavements.

Thickness of flexible pavements can be determined through the use of the following equation:

$$t = \alpha_1\left\{\sqrt{A}\left[-0.0481 - 1.1562\left(\log\frac{CBR}{P_e}\right) - 0.6414\left(\log\frac{CBR}{P_e}\right)^2 - 0.473\left(\log\frac{CBR}{P_e}\right)^3\right]\right\} \qquad \textbf{(B-4)}$$

where

t = total thickness of superior material required above a layer of known strength to prevent shear deformation within this layer of soil, inches

a 1= load repetitions factor, which varies with number of wheels and volume of traffic

P_e = SWL or ESWL2 tire pressure, pounds per square inch. For single-wheel loads, P. = SWL/A. This is an actual tire pressure and is generally equal to the tire inflation pressure. For multiple-wheel configurations, P. = ESWL/A. This is an artificial tire pressure, consistent with use of

the contact area of one tire, and has no relation to actual tire inflation pressure

Thickness requirements for various container handling vehicles were determined for 200 and 10,000 passes through the solution of equation (B-4), and the results of these computations are shown in figures B-13 through B-23.

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[1]Discussed in Technical Report S-71-17 by R. G. Alhvin.

[2]ESWL can be determined by methods given in Miscellaneous Paper 8-73-56 by D. N. Brown and 0. O. Thompson.

Table B-1. Design Criteria Restrictions (200-10,000 Passes)

Traffic Volume in Passes	Restrictions on Use as Design Criteria
200	CBR and thickness requirements shown in table B-2 may be used without restriction for the Shoremaster, Clark 512, Belotti B67b, Hyster H620B, Lancer 3500, P&M 6250-TC, and M52 tractor-trailer. CBR and thickness requirements given in table B-2 may be used if necessary and identified as "tentative criteria" for the LARC LX, LeTro-Porter 2582, and Travelift CH 1150. CBR and thickness requirements given for the LeTro Crane GC-500 shall not be used for criteria in any case except under emergency conditions. The reliability of these requirements is unknown.
10,000	Basic test data for operations of vehicles on unsurfaced soils are limited in scope to data from traffic volumes of less than about 5,000 passes. The reliability of requirements developed by extrapolation for volumes beyond the limits of basic test data is questionable. The thickness and CBR requirements shown in table B-2 for 10,000 passes shall not be used for criteria except under emergency conditions.

Table B-2. CBR and Thickness Requirements for 200 and 10,000 Passes of Container Handling Vehicles Operating on Unsurfaced Soils with Subgrade Strengths of 4 and 10 CBR [a]

						Passes					
						200			10,000		
					Tire		Thickness Requirements, in			Thickness Requirements, in.	
Vehicle	Gross Weight lb	Payload lb	Tire Pressure, psi Inflation	Contact	Contact Area in. ^{2}	Surface CBR	4-CBR Subgrade	10-CBR Subgrade	Surface CBR	4-CBR Subgrade	10-CBR Subgrade
Amphibian											
LARC LX[b]	319,000	120,000	42	42	1898	10	22	0	20	35	16
Straddle Carriers											
Shoremaster	129,200	67,200	100	105	154	9	11	0	17	18	10
Clark 512	164,500	67,200	132	133	210	14	14	9	26	20	12
Belotti B67b	159,800	67,200	125	115	380	14	17	9	27	28	14
Front-Loading Forklift											
Hyster H620B	140,710	62,000[C]	100	145	224	20	19	11	38	35	20
LeTro-Porter 2582	165,200	67,200	70	99	800	18	21	12	35	35	20
Side-Loading Forklift											
Lancer 3500	213,200	67,200	149	150	183	19	20	11	36	35	20
Yard Gantry											
Travelift CH 1150	223,200	67,200	146	146	280	24	22	12	45	36	21
Mobile Cranes											
P&H 6250-TC	396,021	o[d]	100	106	260	16	31	18	30	55	31
LeTro Crane GC-500	708,504	o[d]	35	69	1275	26	32	17	50	56	29
Tractor-Trailer Combination											
M52 Tractor and Trailer	100,000	67,200	80	68	82.5	5	10	0	10	18	0

[a] Unsurfaced soil criteria limited to approximately 10,000 passes.
[b] As is well known, the LARC LX was not specifically designed for container handling. It has been included in this study for comparative purposes because of its known operational capability on relatively low-strength soils.
[c] Maximum payload for the Hyster H620B.
[d] Zero payload while moving.
[e] Criteria do not exist for loads imposed by vehicles on unsurfaced soils. Data shown are based on extrapolation and engineering Judgment.

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Table B-3. Design Criteria Restrictions (200-50,000 Passes)

Traffic Volume in Passes	**Restrictions on Use as Design Criteria**
200	CBR and thickness requirements given in table B-4 may be used without restrictions for the Shoremaster, Clark 512, Belotti B67b, Hyster H620B, Lancer 3500, Travelift CH 1150, and M52 tractor-trailer.
	CBR and thickness requirements given in table B-4 may be used if necessary and identified as "tentative criteria" for the LARC LX, LeTro-Porter 2582, P&H 6250-TC, and the LeTro Crane GC-500.
10,000	CBR and thickness requirements given in table B-4 may be used if necessary and identified as "tentative criteria" for the Shoremaster, Clark 512, Belotti B67b, Hyster H620B Lancer 3500, Travelift CH 1150, and M52 tractor-trailer.
	CBR and thickness requirements given in table B-4 for the LARC LX, LeTro-Porter 2582, P&H 6250-TC, and LeTro Crane GC-500 are not recommended for use as criteria except under emergency conditions.
50,000	A traffic volume of 50,000 passes is so far outside the limits of basic field test data that the reliability of i requirements shown in table B-4 is not known. The CBR and thickness requirements shown in table B-4 shall not be used as criteria except on an experimental basis.

Table B-4. CBR and Thickness Requirements for 200, 10,000, and 50,000 Passes of Container-Handling Vehicles Operating on Soils Surfaced with ISAI Landing Mat and with Subgrade Strengths of 4 and 10 CBR[a]

						Passes								
						200			10,000			50,000		
							Thickness Requirements in.			Thickness Requirements in.			Thickness Requirements In.	
			Tire Pressure, psi		Tire Contact Area		4-CBR	10-CBR		4-CBR	10-CBR		4-CBR	10-CBR
Vehicle	Gross Weight lb	Payload lb	Infl-tion	Contact	in. ^{2}	Surface CBR	Sub-grade	Sub-grade	Surface CBR	Sub-grade	Sub-grade	Surface CBR	Sub-grade	Sub-grade
Amphibian														
LARC LX[b]	319,000	120,000	42	42	1898	3.5	0	0	7	27	0	9	36	0
Straddle carriers														
Shoremaster	129,000	67,200	100	105	154	3.5	0	0	8	22	0	10	32	0
Clark 512	164,500	67,200	132	133	210	5	6	0	11	28	7	14	37	11
Belotti B67b	159,800	67,200	125	115	380	5	8	0	11	26	7	14	34	11
Front-Loading Forklifts														
Hyster H620B	140,710	62,000[c]	100	145	224	6	10	0	13	40	6	19	51	20
LeTro-Porter 2582	165,200	67,200	70	102	800	12	21	6	22	51	21	25	65	27
Side-Loading Forklift														
Lancer 3500	213,200	67,200	149	150	183	6	13	0	14	43	13	17	56	21
Yard Gantry														
Travelift CH 1150	223,200	67,200	146	146	280	6	13	0	14	32	6	17	46	12
Mobile Cranes														
P&H 3250-TC	396,021	0[d]	100	106	260	13	36	10	26	81	32	35	82	32
LeTro Crane GC-500[e]	708,504	0[d]	35	69	1275	15	37	11	23	82	33	25	99	44
Tractor-Trailer Combination														
M52 Tractor and Trailer	100,000	67,200	80	68	82.5	2.5	0	0	5	15	0	7	20	0

[a] M8A1 landing mat was not designed for use with large loads imposed by most of the equipment listed nor for traffic volumes exceeding about 2000 passes.

[b] As is well known, the LARC LX was not specifically designed for container handling. It has been included in this study for comparative purposes because of its known operational capability on relatively low-strength soils.

[c] Maximum payload for the Hyster H620B.

[d] Zero payload while moving·

[e] Criteria do not exist for loads imposed by vehicles on M8A1 landing mat. Data shown are based on extrapolation and engineering judgment·

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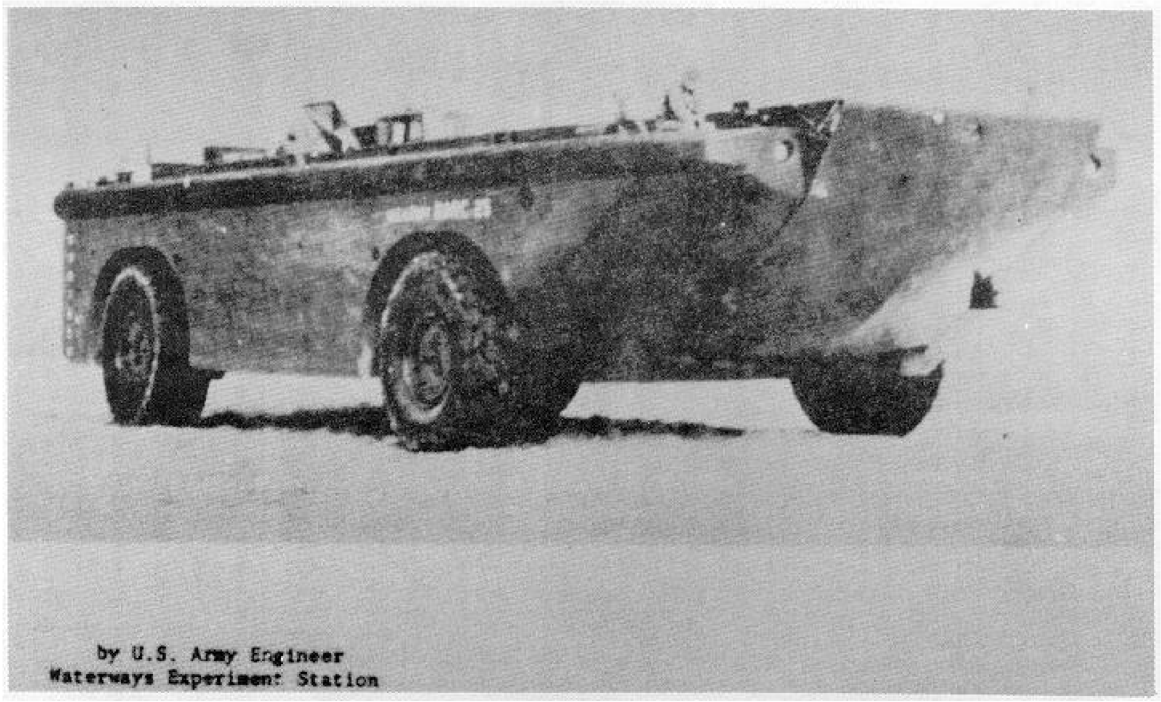
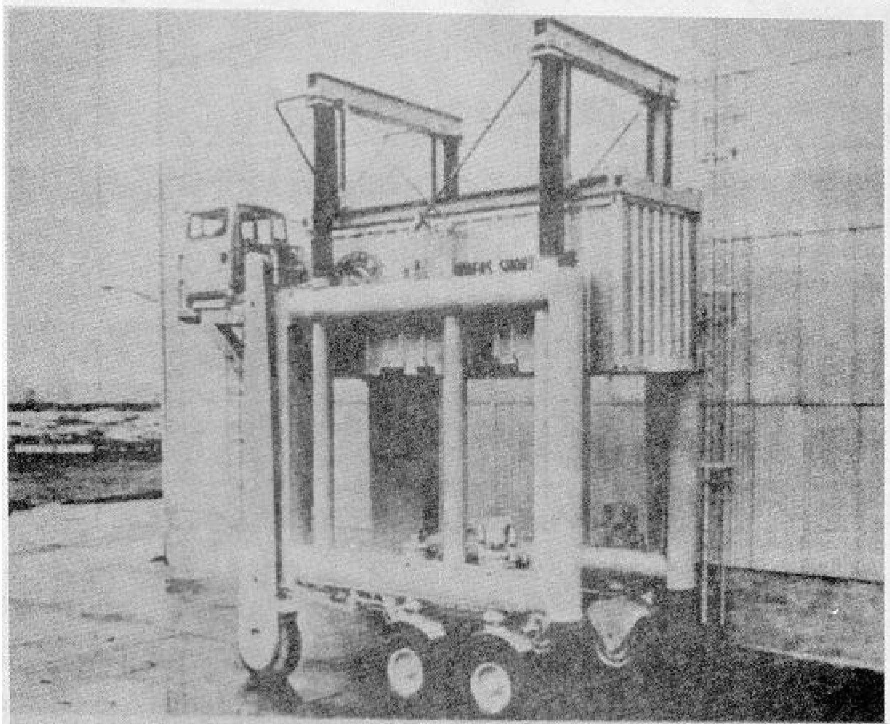


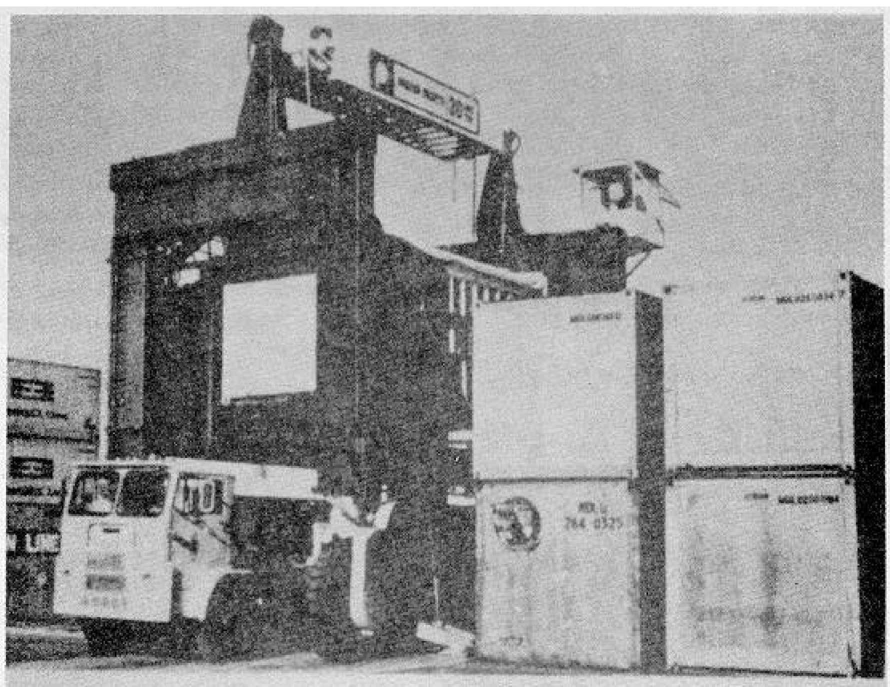
Figure B-1. LARC LX.

Figure B-2. Shoremaster.



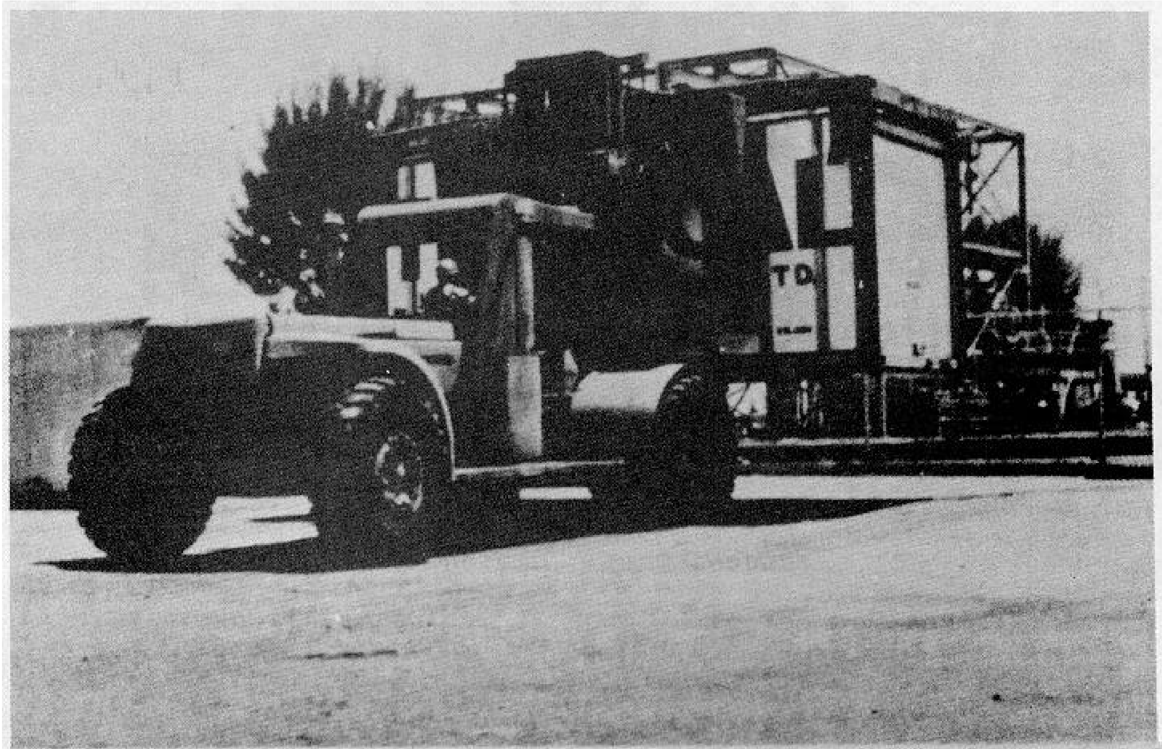
(Courtesy of Clark Equipment Company,
Battle Creek, Michigan)

Figure B-3. Clark 512.



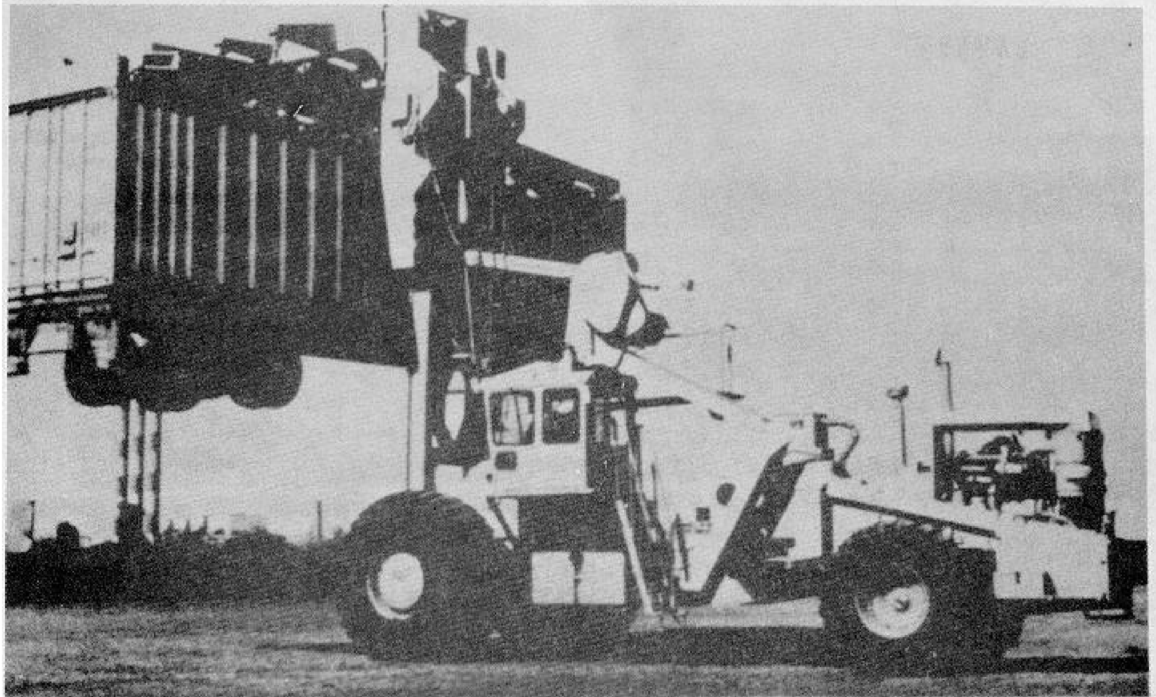
(Courtesy of Paceco,
Alameda, California)

Figure B-4. Belotti B67b.



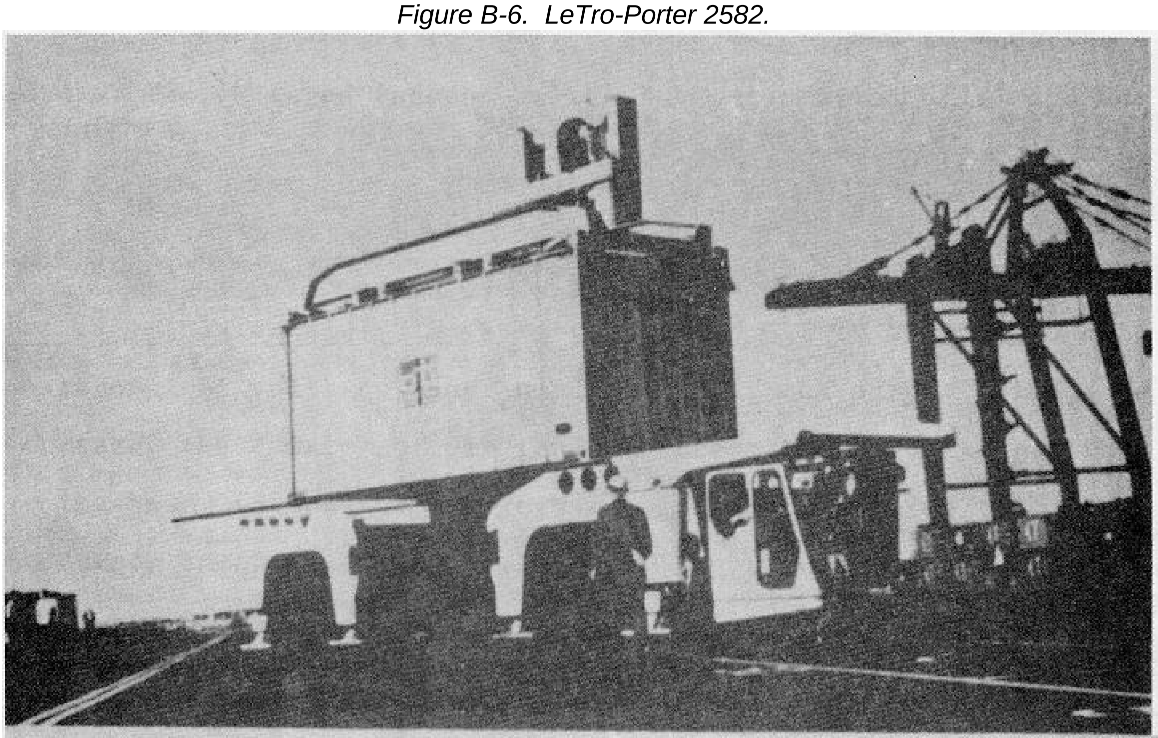
(Courtesy of Hyster Company,
Portland, Oregon)

Figure B-5. Hyster H620B



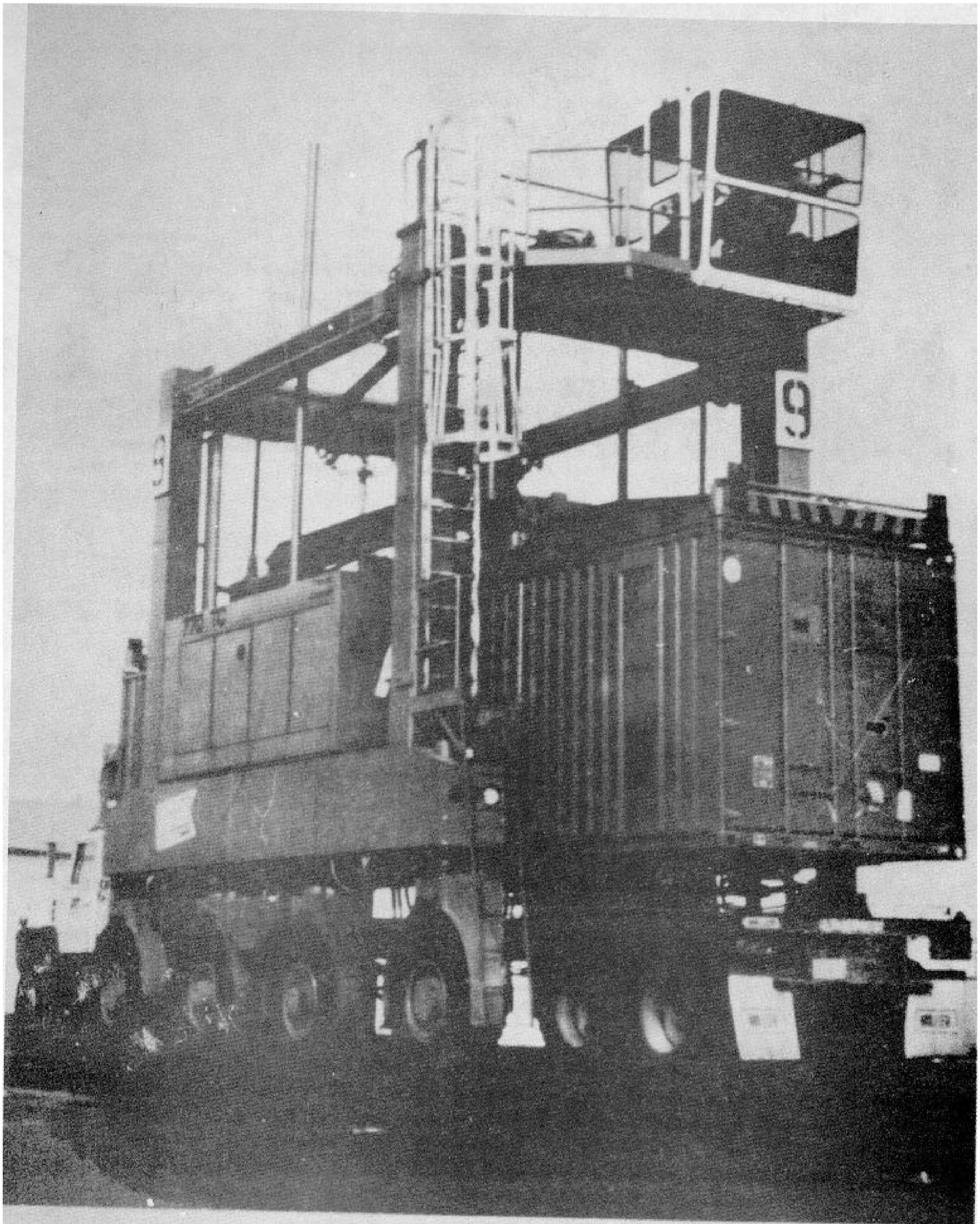
(Courtesy of Marathon-LeTourneau Company, Longview, Texas)

Figure B-6. LeTro-Porter 2582.



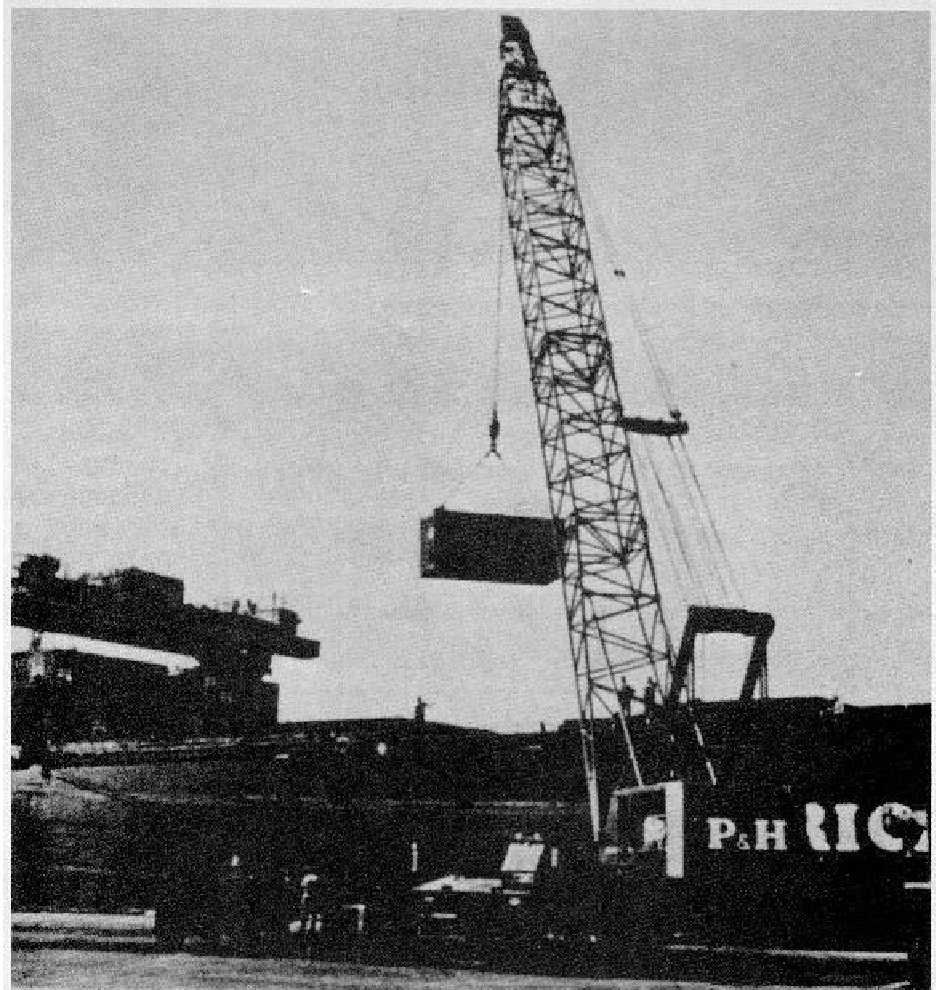
(Courtesy of Allis-Chalmers, Matteson, Illinois)

Figure B-7. Lancer 3500.



(Courtesy of Drott Manufacturing Company, Wausau, Wisconsin)

Figure B-8. Travelift CH 1150.



(Courtesy of Harnischfeger Corporation,
Milwaukee, Wisconsin)

Figure B-9. P&H 6250-TC.

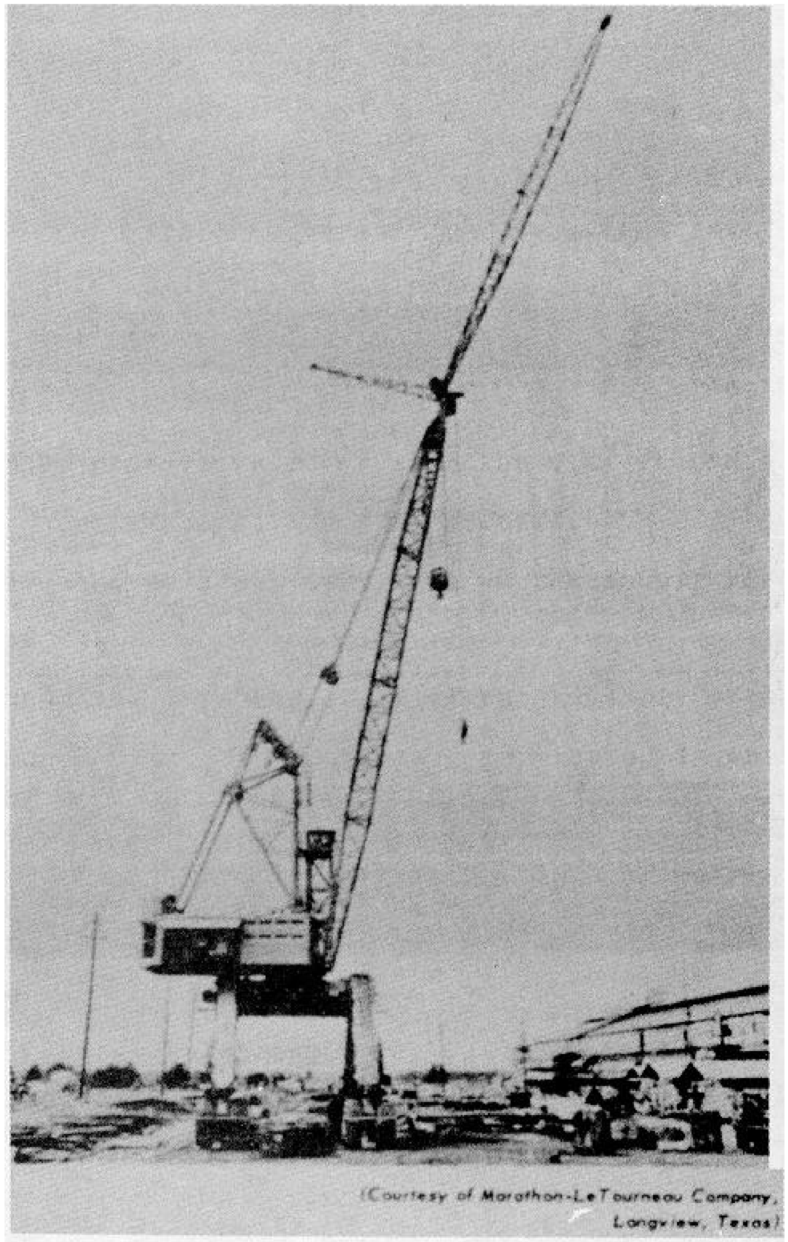


Figure B-10. LeTro Crane GC-500.

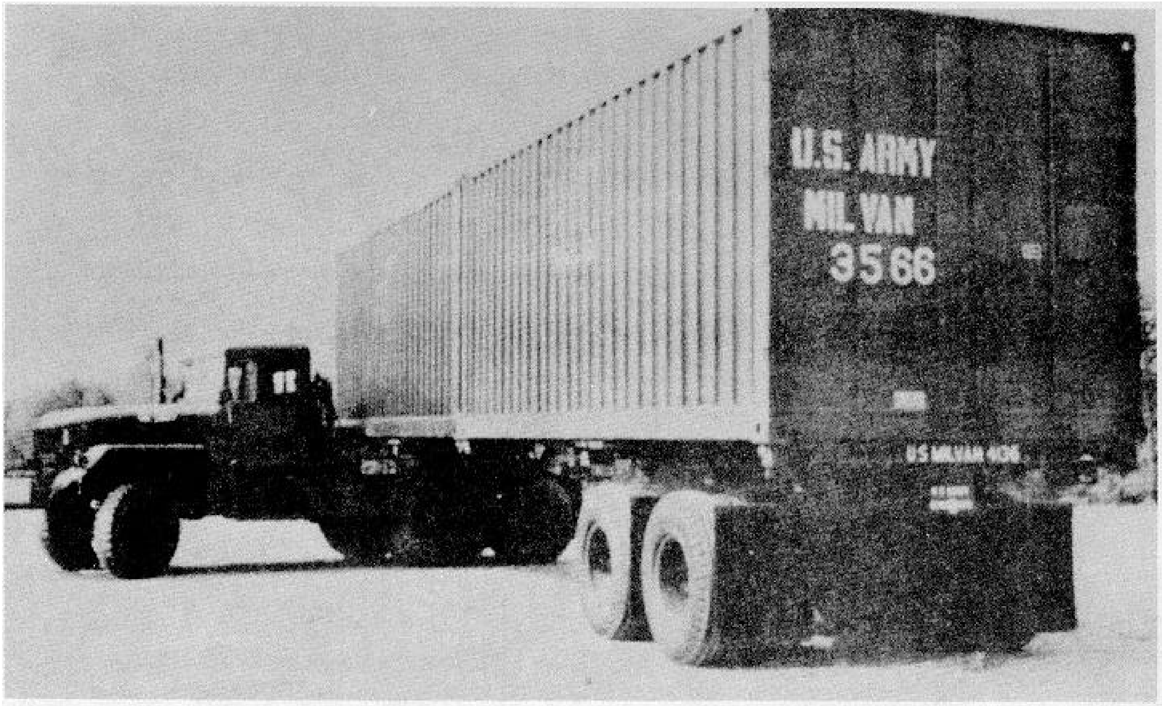


Figure B-11. M52 Tractor-trailer.

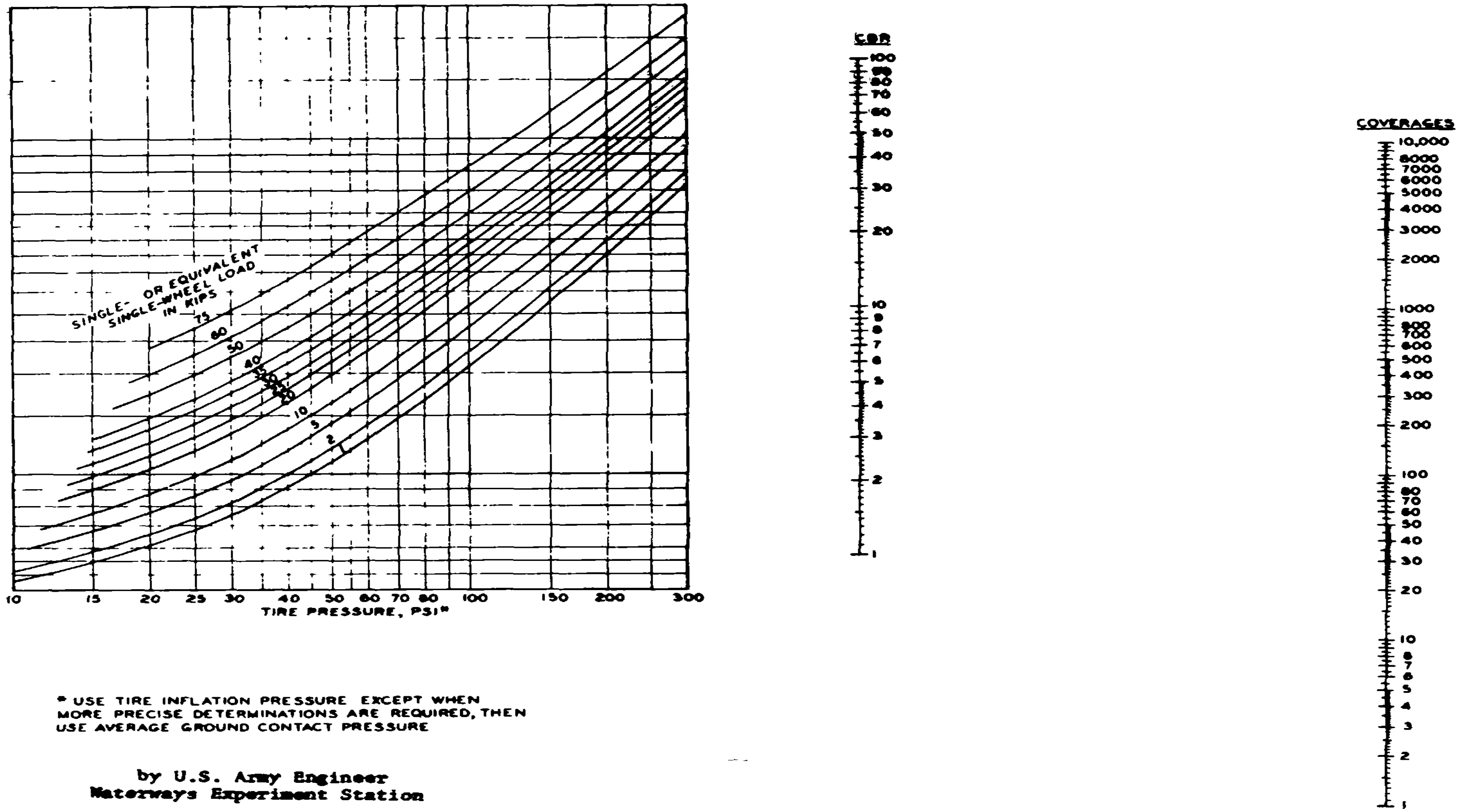
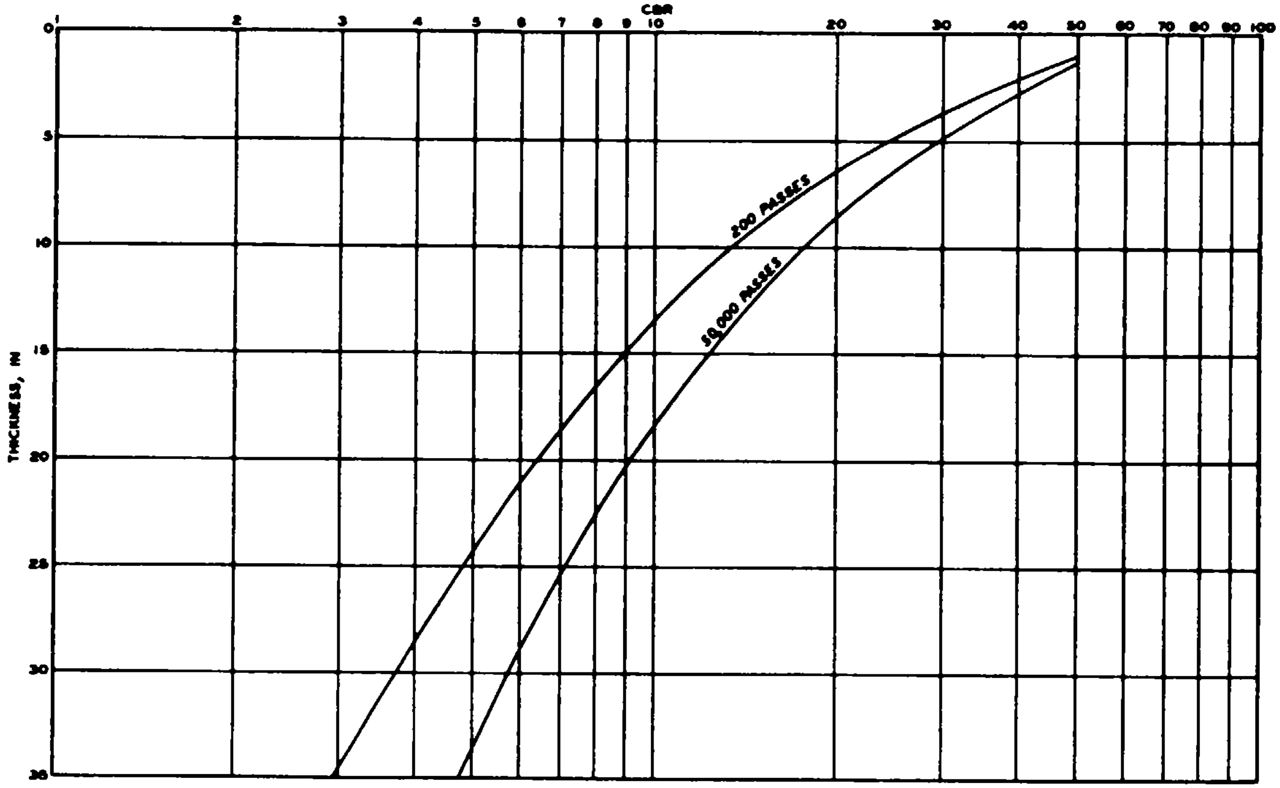


Figure B-12. CBR required for operation of aircraft on unsurfaced soil.



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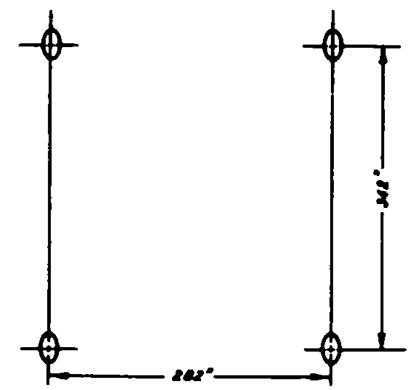
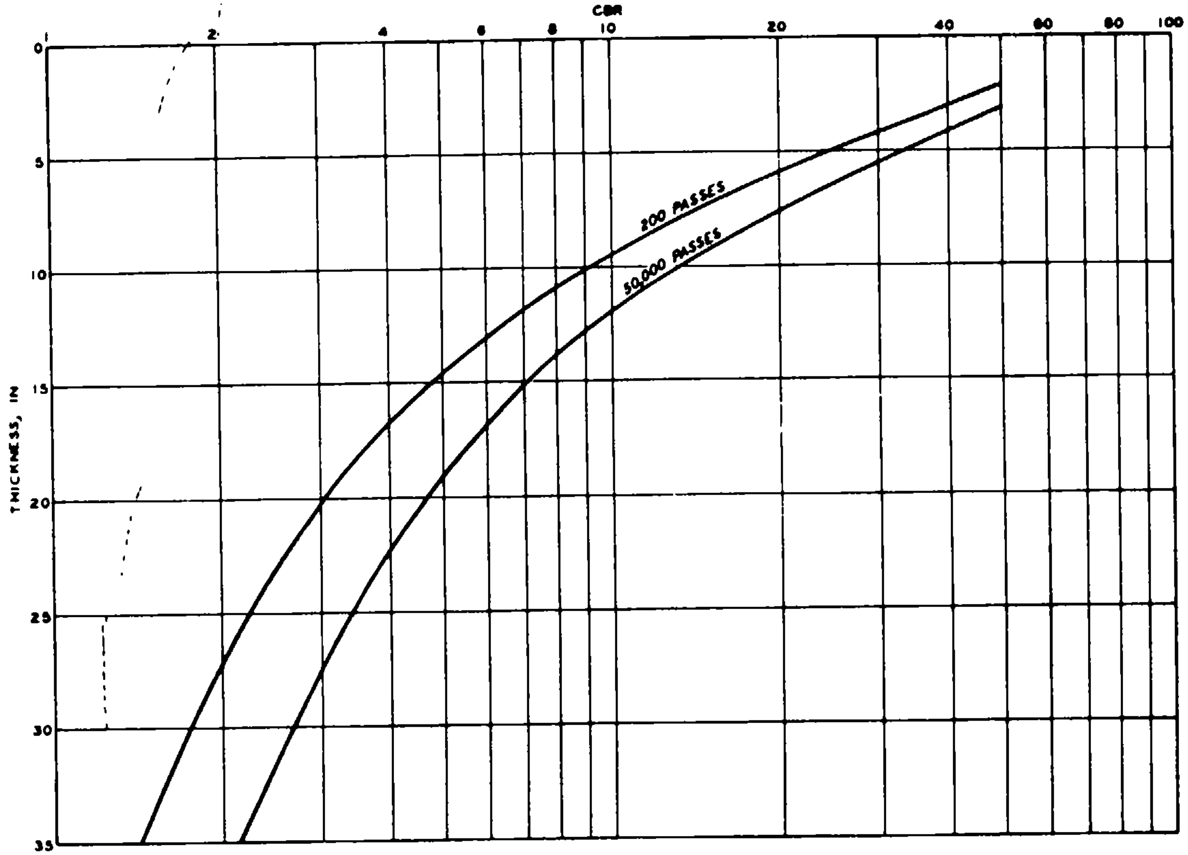
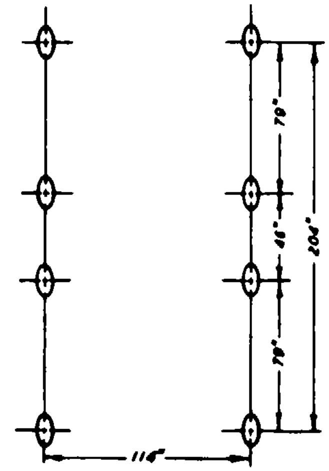


BASIS FOR DESIGN CURVES		
GROSS WEIGHT	=	319,000 LB
SINGLE-WHEEL LOAD	=	79,750 LB
TIRE INFLATION PRESSURE	=	42 PSI
CONTACT AREA	=	1,898 IN.^{2}
PAYLOAD	=	120,000 LB

WHEEL CONFIGURATION

Figure B-13. Flexible Pavement Design Curves for LARCLX (amphibian).





BASIS FOR DESIGN CURVES

GROSS WEIGHT	=	129,200 LB
SINGLE-WHEEL LOAD	=	16,150 LB
TIRE INFLATION PRESSURE	=	100 PSI
CONTACT AREA	=	164 IN.^{2}
PAYLOAD	=	67,200 LB

WHEEL CONFIGURATION

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Figure B-14. Flexible Pavement Design Curves for Shoremaster (straddle carrier).

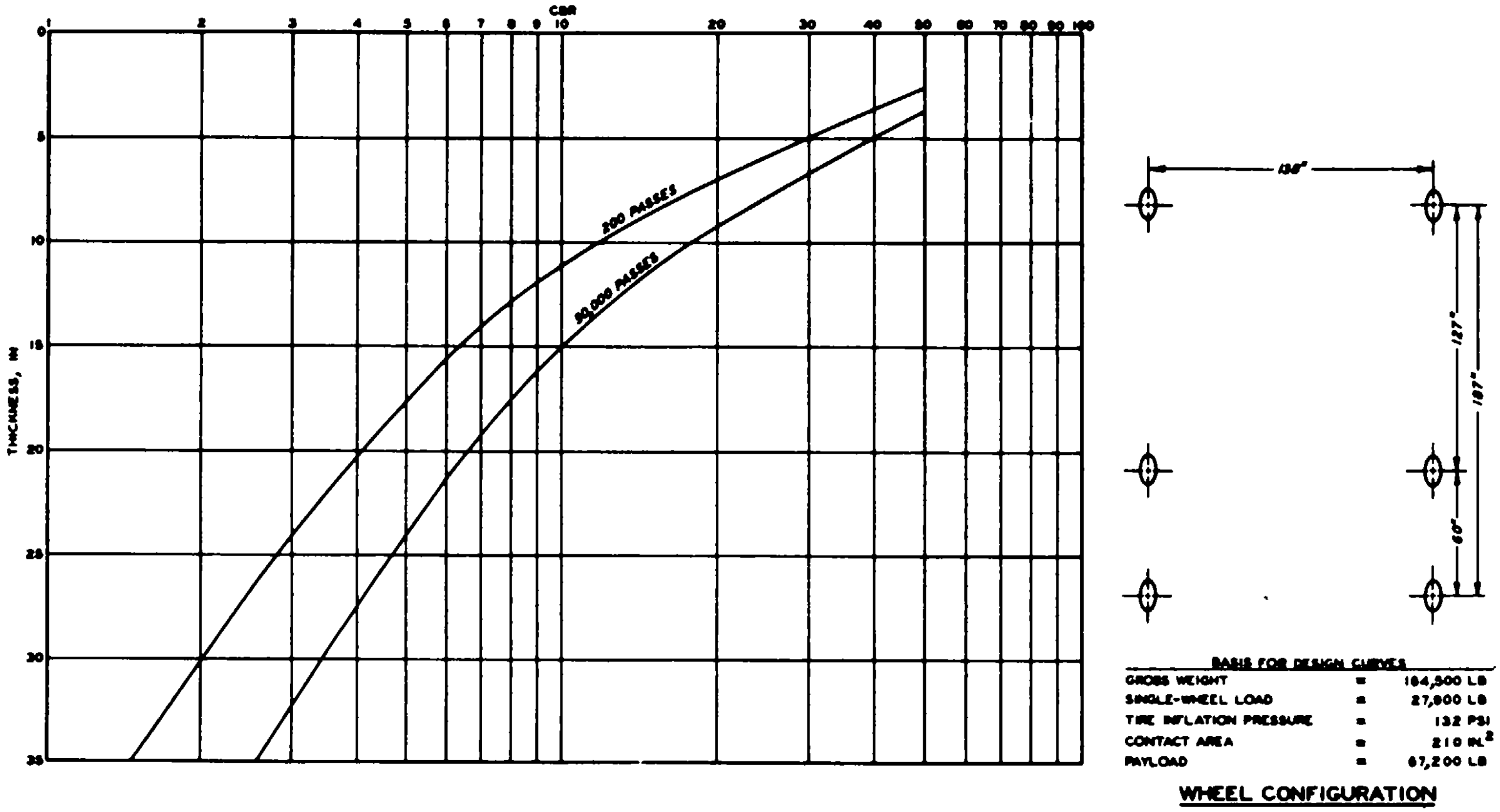

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Figure B-15. Flexible Pavement design Curves for Clark 512 (straddle carrier).

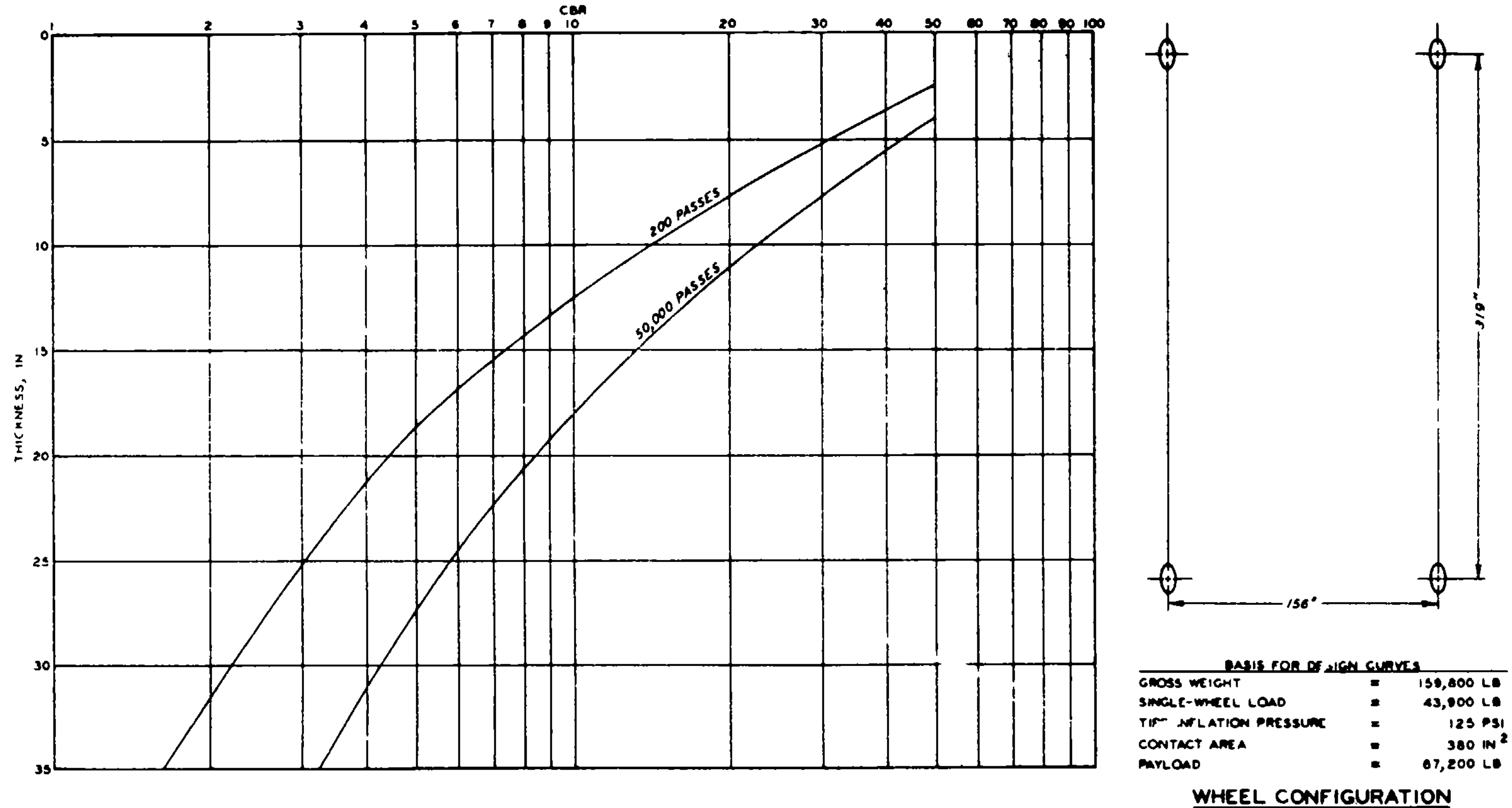

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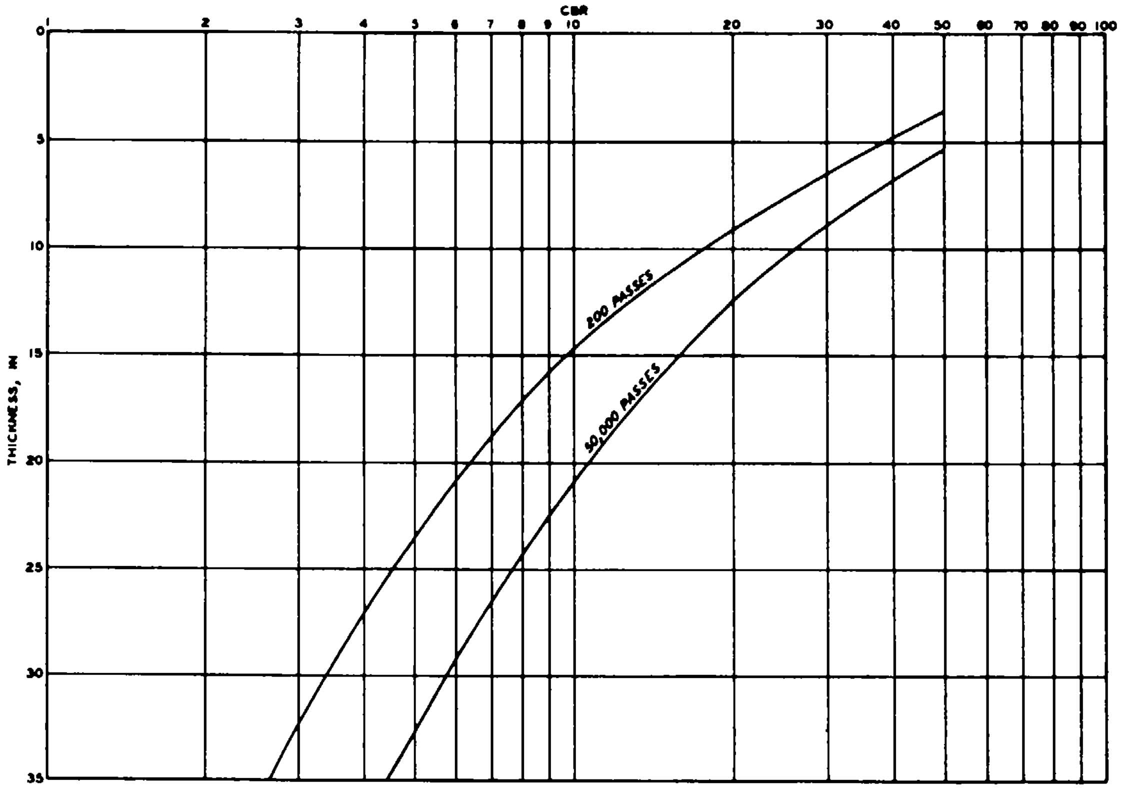
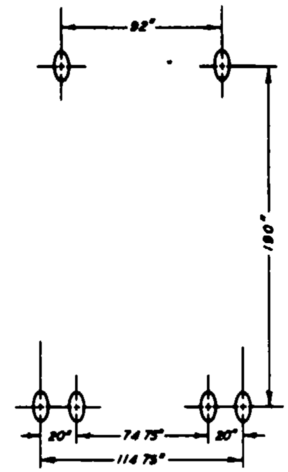
Figure B-16. Flexible Pavement Design Curves for Belotti B67b (straddle carrier).





BASIS FOR DESIGN CURVES		
GROSS WEIGHT	=	140,710 LB
SINGLE-WHEEL LOAD	=	32,500 LB
TIRE INFLATION PRESSURE	=	100 PSI
CONTACT AREA	=	224 IN.^{2}
PAYLOAD	=	62,000 LB

WHEEL CONFIGURATION

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Figure B-17. Flexible Pavement Design Curves for Hyster H620B (front-loading forklift)

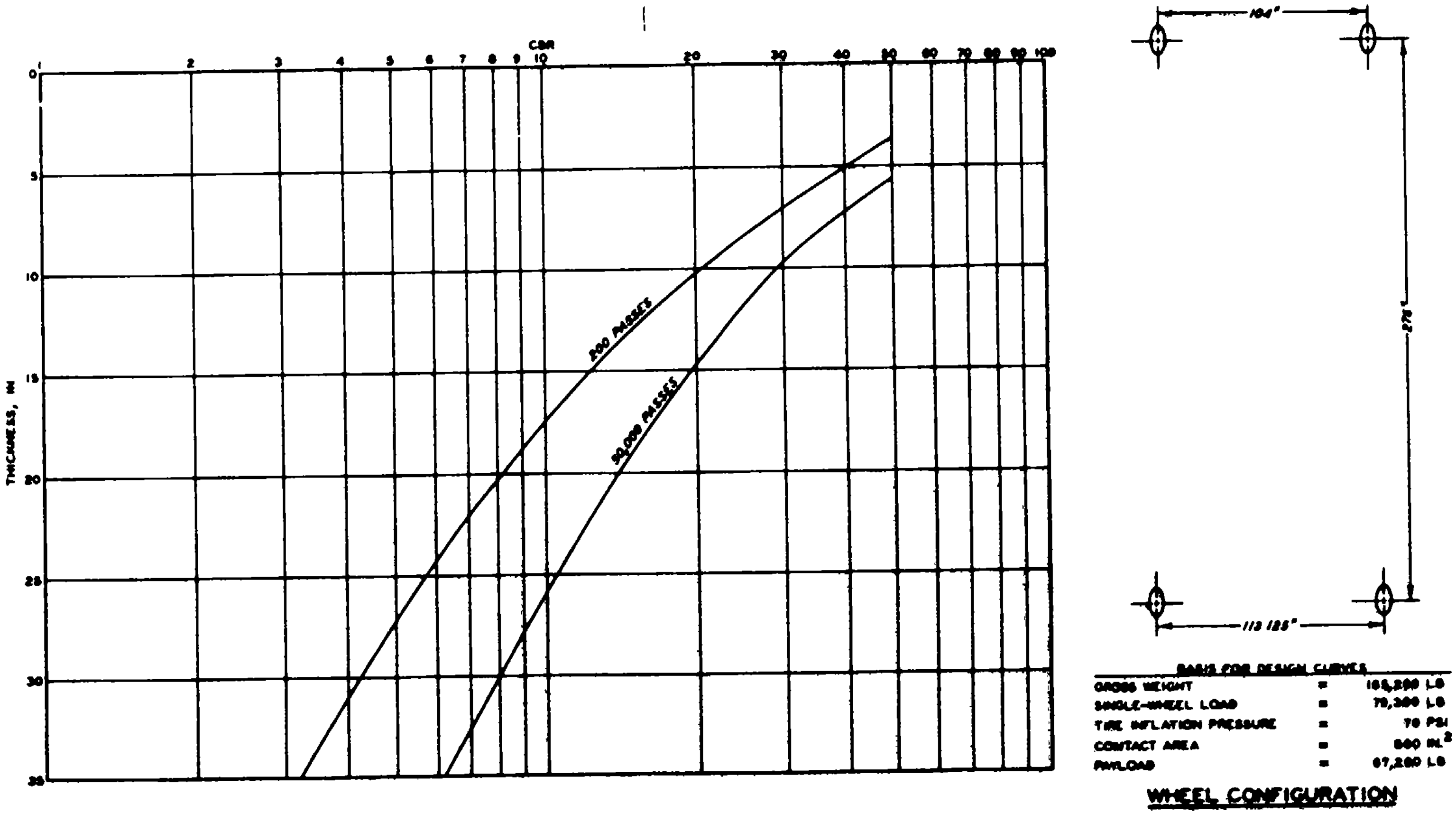

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Figure B-18. Flexible Pavement design Curves for LeTro-Porter 2582 (front-loading forklift).

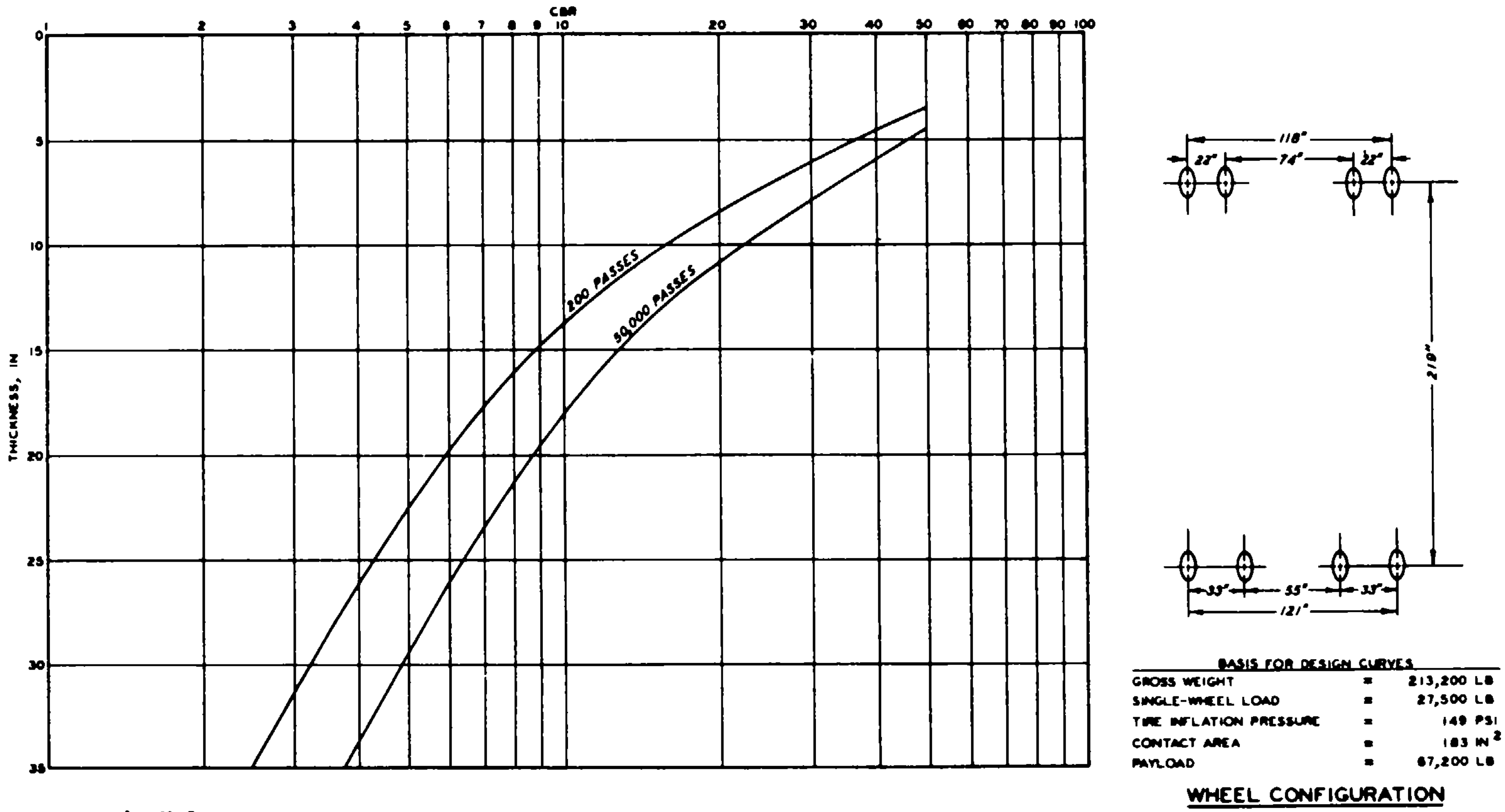

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Figure B-19. Flexible Pavement Design Curves for Lancer 3500 (side-loading forklift).

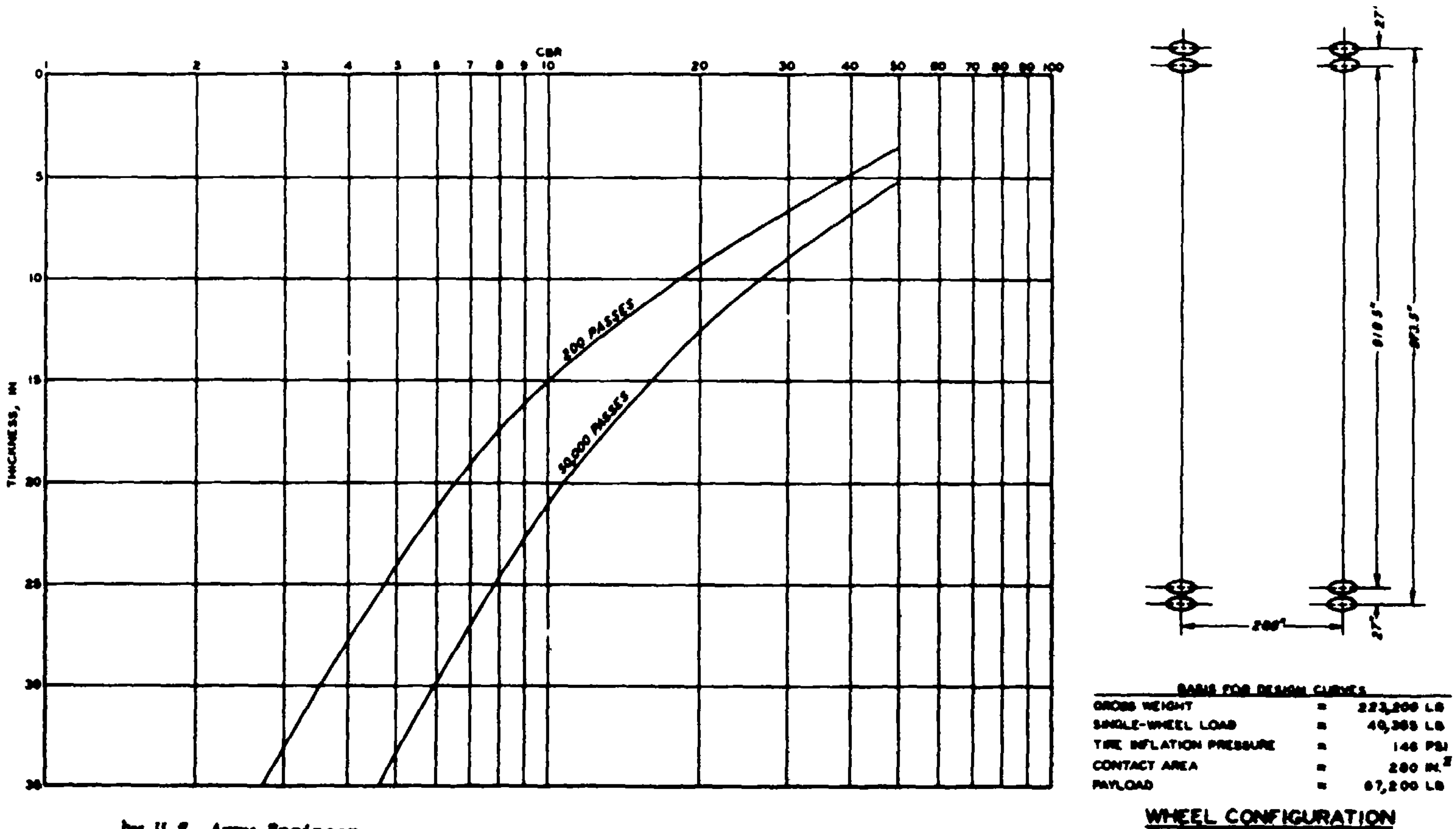

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Figure B-20. Flexible Pavement Design Curves for Travelift CH 1150 (yard gantry).

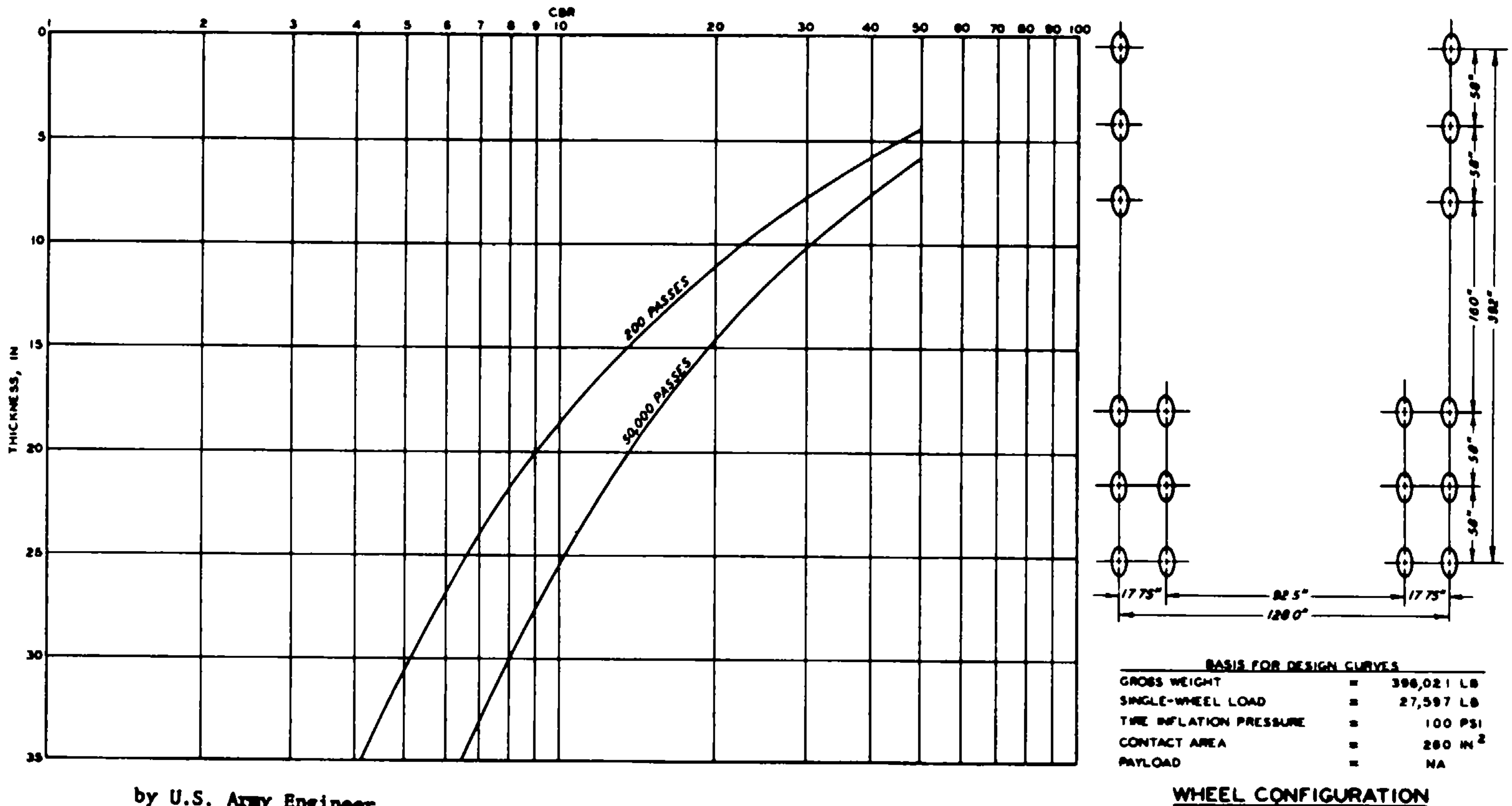

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Figure B-21. Flexible Pavement Design Cure for P&H 6250- TC(mobile crane).

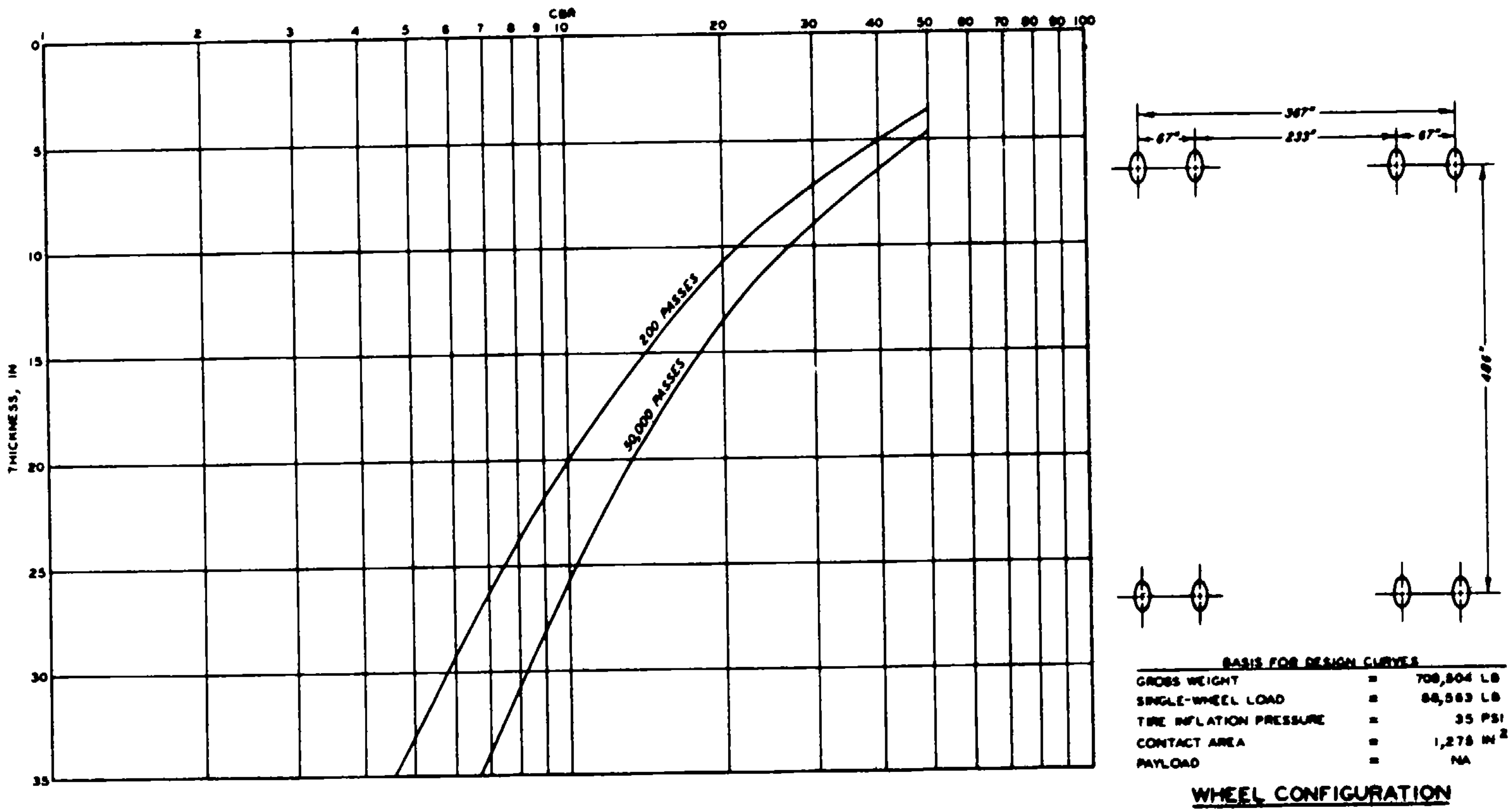

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Figure B-22. Flexible Pavement Curves for LeTro Crane GC-500 (mobile gantry crane).

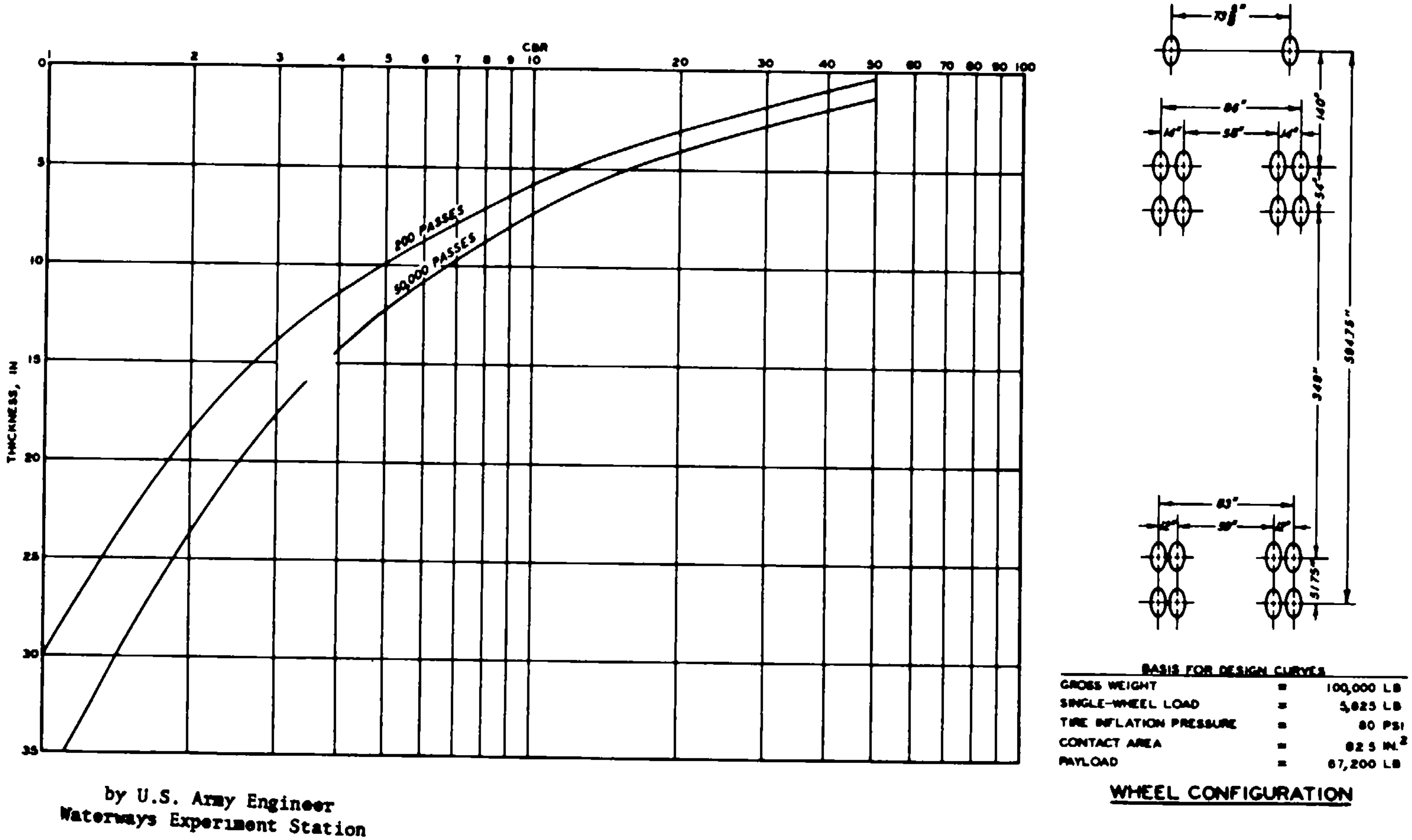

Figure B-23. Flexible Pavement Design Curves for M52 Tractor and Trailer (truck-trader combination)